A GEOHYDROLOGIC EVALUATION OF GLACIAL DRIFT IN A PRE-GLACIAL VALLEY NEAR MINOT, NORTH DAKOTA

BY

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INTRODUCTION

In late 1963, a ground-water investigation was begun in and near the city of Minot, North Dakota. The study was conducted by the U. S. Geological Survey, in cooperation with the North Dakota State Water Commission and the city of Minot in order to reevaluate the municipal water-supply problems. Information resulting from this study suggested the existence of a pre-glacial valley trending south-southwest through the city of Minot. (Pettyjohn, 1967) At least locally, the valley, which is cut deeply into the bedrock surface, contains more than 200 feet of saturated sand and gravel. Elsewhere the valley is filled either with fluvial deposits consisting mainly of silt or with glacial till.

Purpose and Scope of This Investigation

This report is based on data from Akin (1946), Pettyjohn and Hills (1964), Pettyjohn (1967,1968), and subsequent unpublished investigations. The purpose of this report is to determine;
(1) the location and size of the buried pre-glacial valley that trends through the Minot area; (2) the areal extent and thickness of the sand and gravel deposits buried within the pre-glacial valley, and (3) to evaluate the various techniques used in order to determine the most useful methods of aquifer evaluation.

Acknowledgments

Most of the test holes were drilled by the North Dakota State Water Commission. To the Commission, U. S. Geological Survey, and all others who gave of their time to make available to the author pertinent data on test holes and well logs, acknowledgment is given. Also grateful acknowledgment is given to Wayne A. Pettyjohn, Associate Professor of Geology at The Ohio State University for his invaluable aid and assistance.

Well and Test Hole Numbering System

The well numbering system used in this report is based on the U. S. Bureau of Land Management's grid system. The first number in a well-location number denotes the township north of a base line, while the second number is the range west of a principal meridian. The third number indicates in which section of that township the well is located. The lowercase letters after the section number indicate where in the section the well is located. The letter "a" refers to the northeast quarter; "b", the northwest quarter; "c", the southwest quarter; and "d", the southeast quarter. Succeeding letters refer to the quarter-quarter and the quarter-quarter-quarter section, or 10-acre tract. Using this system, which is illustrated in figure 2, the designation 155-82-15 daa would indicate that this well was located in the SE1/4 NE1/4 NE1/4 of sec. 15, T. 155 N., R. 82 W.

LOCATION AND GENERAL FEATURES OF THE AREA

The Minot area is located along the Souris River in Ward County in

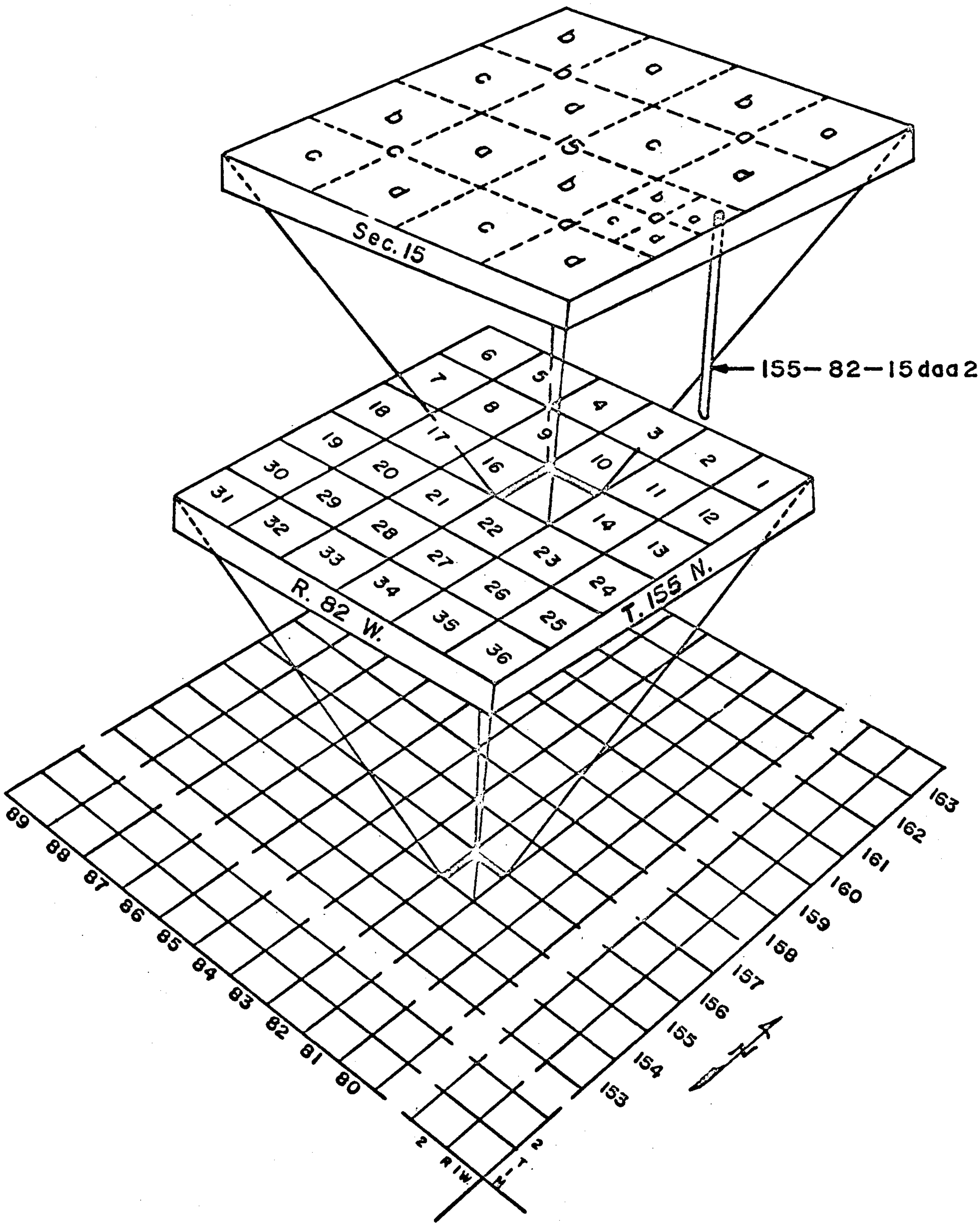

FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

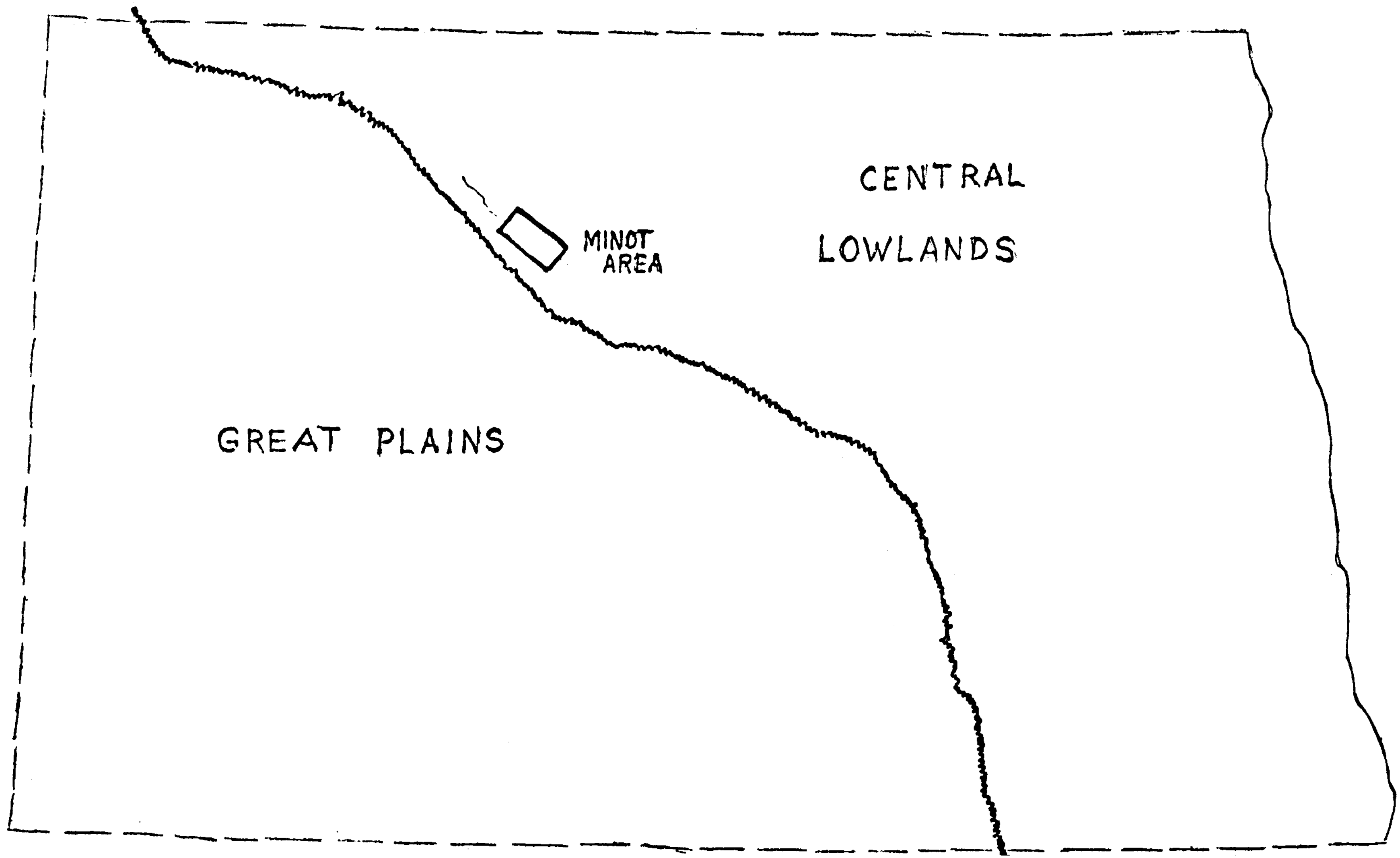

FIGURE 1. Map Showing Physiographic Provinces and Location of Minot Area in North Dakota

northwest North Dakota (fig. 1) and includes an area of about 24 square miles. The area is close to the western edge of the Central Lowland physiographic province. Topographically the area is relatively flat with a local relief of about 100 feet. Along the walls of the Souris River valley, however, maximum topographic relief reaches about 250 feet.

The climate in the Minot area is semiarid. The average annual precipitation is about 15.6 inches although departures from the average may be large in any year. Close to half the annual precipitation is received during May-July in short, heavy summer thunderstorms. The average temperature at Minot is close to 40.0° F. with an annual temperature range of about 150°F.

The area around Minot is a sparsely populated farming and ranching area with some coal mining taking place. Minot, and the adjacent Minot Air Force Base have a total population of about 50,000. The city is served by two main railroads and three federal highways. The city is important to the area as it is the principal shipping point and business center for most of northwestern North Dakota and adjacent parts of Canada.

GEOLOGY

Tertiary

The bedrock in the Minot area is the Fort Union Formation of Tertiary age. The formation is divided into three members, in descending order, the Tongue River, Cannonball, and Ludlow Members. The youngest member, the Tongue River, underlies most of the Minot area. It is composed of about 255 feet of continental deposits of clay, sandstone, and lignite.

In pre-Pleistocene time, the Minot area had evolved into a badland type region. This is, in part, shown by the topographic map of the bedrock surface (plate 1). The valleys were wide with generally flat bottoms and somewhat steep walls.

Before glaciation, the Minot area was drained by northward flowing rivers that flowed into the Hudson's Bay drainage system. The valley described herein was probably typical of rivers in the area at that time. It had a wide floodplain ranging from one to two miles wide with steep valley walls. Due to the causative factors of the badland type weathering, vegetation and rainfall, were probably sparse resulting in large amounts of sediment transport and deposition by the rivers. Also, most rivers probably had extensive meander patterns and low gradients.

Quaternary

During the glacial age the advances and retreats of the ice sheets slowly smoothed off the topography. High areas were planed off and low areas were filled. During this time alluvial deposits, consisting mainly of sand and gravel, were buried by glacial deposits. The advancing ice sheets gradually disrupted the pre-glacial drainage system. The previously northward flowing rivers were dammed by the glaciers. This first created a ponding effect and finally a complete reversal of the drainage. During the ponding stage locally alternating layers of silt and sand were deposited. The ancient river may first have reversed and flowed south in the same valley and finally ceased to exist as the valley was filled. During glacial time the whole of the Minot area was thus covered by various glacial deposits.

The entire area is mantled by glacial drift and alluvium, except for a few small outcrops of bedrock. The topography of the bedrock is the primary control on the total thickness of the glacial material, which ranges from 450 feet beneath the upland surfaces to less than 50 feet near streams and rivers.

EVALUATION TECHNIQUES

Introduction

This report deals mainly with four methods of evaluating glacial sand and gravel deposits and their application to geohydrologic studies. The four methods, all of which involve the use of maps, are: lithofacies, clastic-ratio, isopach, and center of gravity.

Specific details concerning well or test hole data were compiled on data sheets (see appendix). The data included information of wells and test holes drilled in the area during previous ground-water investigations. This information included lithologic logs, electric logs, graphic logs, driller descriptions, and other basic ground-water data.

The base map for this report was modified from U. S. Geological Survey 7.5 minute sheets: Minot, North Dakota; Burlington SE, North Dakota; and Surrey, North Dakota.

Because of the nature of this report, different variables and, accordingly, sources of error are introduced. Primary sources of error are the author's interpretation of data given in the various logs and the accuracy of the driller's descriptions. Limits were therefore set (Table 3) for interpreting logs and descriptions to

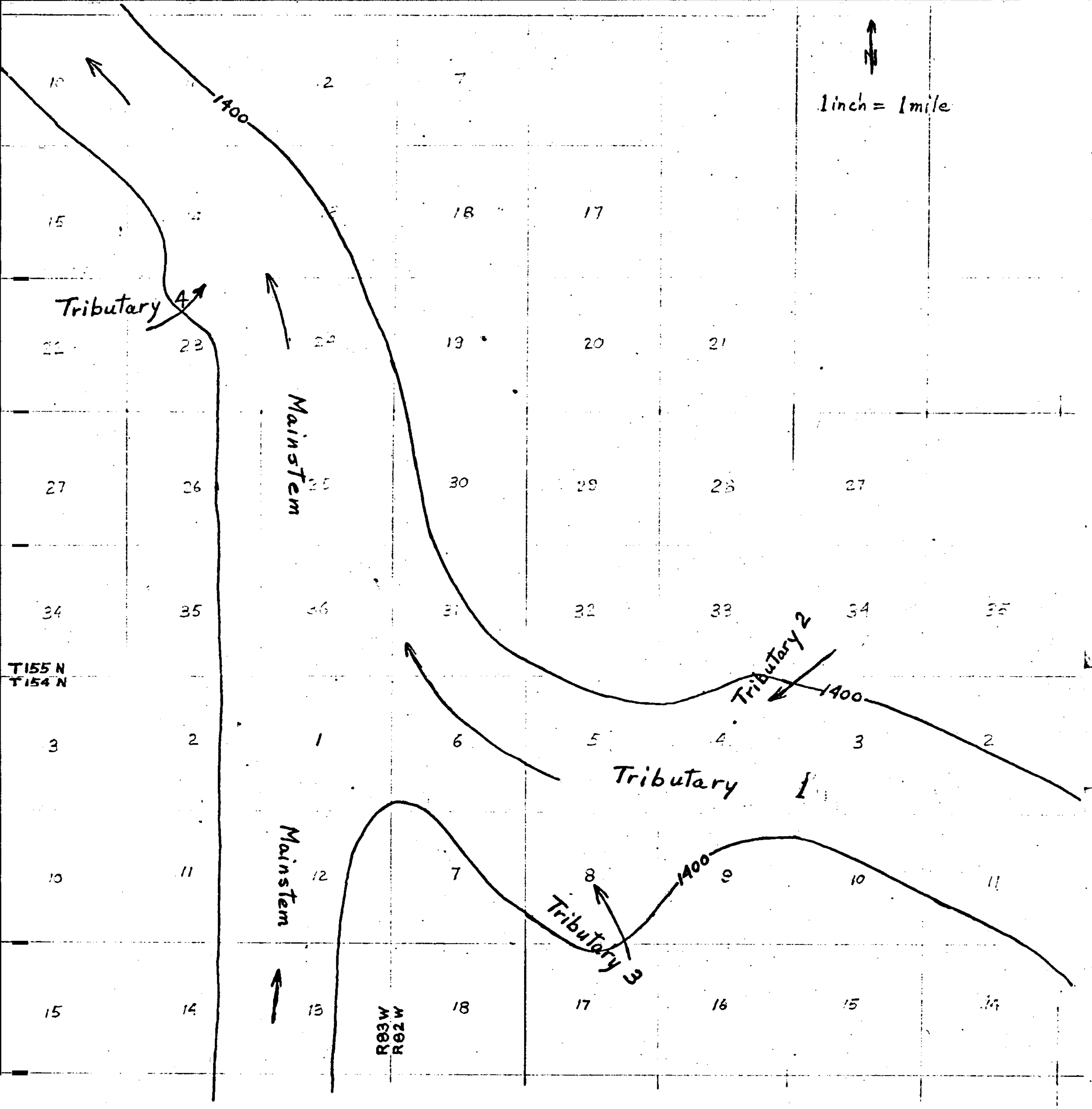

FIGURE 3. Map of Study Area, Showing Location of Mainstem and Tributary Valleys referred to in this report.

minimize or at least standardize errors. Because of a limited number or complete lack of test holes in certain areas, certain deductions were necessarily made.

Configuration of the Bedrock Surface

The basis of this study was largely dependent upon determining the location and size of the buried valley. This was achieved by finding the altitude of the bedrock in all holes that penetrated it. The elevations were plotted and contoured with a 50-foot interval. The valley apparently has a northerly gradient and trends north - northwest through the city of Minot. The geohydrologic study was confined within the 1400 foot contours, which best outlines the general trend of the valley (plate 1). The bedrock surface of the area has a main valley trending north - south with a main tributary entering this valley from the east. Two minor tributaries entering the main tributary are suggested by the contours, as is another entering the main valley from the west. The main valley and tributaries will hereafter be referred to as the mainstem and tributaries 1,2,3, and 4 as shown in figure 3.

Lithofacies Clastic-Ratio Maps

The description and preparation of lithofacies clastic-ratio maps has been described by various authors such as Krumbein and Sloss, 1951 and Pettijohn, 1957. However, the application of these maps in glaciated areas has only recently been used (Pettyjohn and Randich, 1966).

The basis of lithofacies clastic-ratio maps is a rock texture percentage triangle using the end-member concept (fig. 3). The apexes of the triangle are considered, 100 percent sand, 100 percent gravel and boulders, and 100 percent clay and silt, respectively. The triangle may be set up using different end members, but for the purpose of this paper these three were considered most appropriate. The triangle is divided into nine parts according to conventional textural classifications. These units are defined in table 1.

Table 1

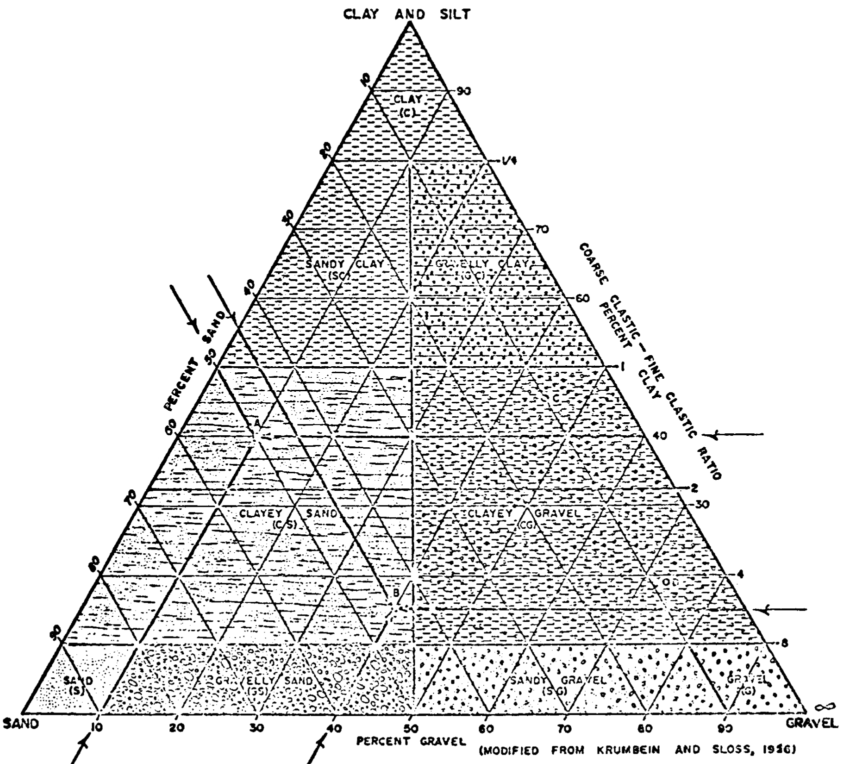

FIGURE I—LITHOFACIES TRIANGLE

Lithology	Percentage
Gravel	90
Sand	90
Sandy gravel	50-80, gravel; 20-50, sand, clay and silt
Gravelly sand	50-80, sand; 20-50, gravel, clay and silt
Clayey gravel	50-80, gravel; 20-50, clay and silt, and sand
Clayey sand	50, sand; 20-50, clay and silt, and gravel
Gravelly clay	50-80, silt and clay; 20-50, sand, and gravel
Sandy clay	50-80, silt and clay; 20-50, sand and gravel
Clay and silt	80

(after Pettyjohn and Randich, 1967)

In using the triangle, the percent of each end member within a particular unit is plotted and that point thus defines the lithologic characteristics of the specific unit according to table 1.

Because of the narrow limits which must be used in aquifer studies a finer differentiation between points on the triangle must be introduced. This is accomplished by the addition of ratio lines to the triangle. The ratio lines used in this study determine the relationship between the coarse fraction (sand and gravel) and the fine fraction (clay and silt). This is termed the coarse-fine ratio and is computed as follows:

$$\text{coarse-fine ratio} = \frac{\text{sand + gravel}}{\text{clay + silt}}$$

Six ratio lines (table 2) were used and contoured on the maps to aid interpretation.

Table 2

Percentage	Ratio
20	1/4
50	1
67	2
80	4
89	8
100	∞

(after Pettyjohn and Randich, 1967)

The maps in this report were prepared by analyzing geologists' and drillers' logs. The use of logs of this type may create problems, because the terms used by different individuals may have different meanings. Accordingly, the following percentages were used as approximate guidelines for modifying terms used in logs.

Table 3

Modifying terms found on geologists or drillers' logs	Percent sand or gravel
clean ---	90-100
interbedded	25-30
silty, sandy, etc.	25
slightly --------	10
fluvial sediment	15

Since it was decided to confine this study to the material in the buried valley, the control datum used was the 1400 foot elevation (above sea level). In all cases this elevation is below the present land surface. This restriction limits some of the benefits of lithofacies maps since an interval, which includes the ground surface, should indicate areas of natural recharge or discharge, areas of confining layers, and areas of water-table and artesian conditions. Much information still can be shown by these maps. If some laboratory data, field permeability test data or aquifer test data are available, areas of equal permeability, and transmissibility may be determined. It has been shown that specific yield and permeability roughly correspond to the coarse-fine clastic ratio lines. However, where the coarse-fine ratio is less than 2, permeability decreases rapidly.

In this study the rock unit was divided into three 50-foot intervals. The first unit represents the interval from 1350 to 1400 feet above sea level, the second unit from 1300 to 1350 feet, and the third from 1300 feet to bedrock. Because of rapid facies changes and complexity of the aquifer a 50-foot interval was needed to show the lithologic relationships. Using certain limits, the lithology of each unit was plotted on the lithofacies triangle and its lithology and coarse-fine ratio was plotted on each map.

The interval from 1350-1400 is shown on plate 2. It shows that the major thickness of sand and gravel is located in tributary 1 and appears to be thickening eastward. The deposits gradually thin as tributary 1 enters the mainstem valley. Although control is limited, most of the mainstem valley contains clay deposits, except where tributary 4 enters it. Here sand and gravel is present due to the effect of tributary 4. The movement of sand and gravel from tributary 4 into the slower moving mainstem would have caused the heavier bedload to be quickly deposited. Although the major sand and gravel thickness appears in the middle of tributary 1, tributary 2 may have had some influence on this deposit. This, as well as the higher concentration of gravel from tributary 3 is shown by the clastic ratio lines.

Plate 3 indicates that the sand and gravel deposits from 1300 to 1350 feet are more extensive in tributary 1 than in the interval shown on plate 2. Gravel is well developed even into the mainstem where it quickly thins. The slight influence of tributary 2 on the major aquifer in tributary 1 in the first interval now seems to be a major source of sand and gravel. This may be the cause for the greater length of the aquifer in tributary 1. While the sediments in the mainstem valley are still primarily clay, the sand and gravel from tributary 4 are still in evidence although less than in the first interval. The increase in gravel from tributary 3 which was seen in the 1350-1400 foot interval is not present in this interval.

The third interval, bedrock to 1300 feet, is shown on plate 4. This interval has the least control of the three, but it still shows the probable relations. The main aquifer is still present in tributary 1 and has increased in areal extent to the west. An interesting difference however is the fact that all this deposit seems to have had its origin from tributary 2, whereas in the first and second intervals the major source was from the east, in tributary 1. Lack of data in the northern part of the mainstem valley has restricted mapping of this interval, although the presence of any aquifer seems doubtful. Although sediments which are lower than the clastic-ratio line 2, can seldom be used for ground water development, it may be noted that the southern part of the mainstem valley has a higher sand content than in the first two intervals.

The origin of the various deposits present may be quite complex. Before the ice age the river system apparently flowed to the north. With the coming of the ice sheets the river was dammed. With the drainage dammed to the north of this area would come a rise in the local base level. This could have caused the deposition of heavier materials such as sand and gravel if there were sources for them. Later during a reversal of the drainage there would have been large amounts of sediment being carried and deposited by the streams and rivers. With the glaciers overriding the area, sand and gravel may have been locally deposited and then sorted with a return to the original drainage. The river system was finally completely altered by ice damming or other means and now flows south through the area as the Souris river.

It can now be seen that much of the complex stratigraphy of these deposits is well illustrated by this series of maps. The main aquifer is somewhat uniform throughout its entire thickness and appears to have a good potential for development of ground-water supplies. The sand and gravel in the area of tributary 2 appear to be hydrologically connected to bedrock, and depending on head conditions may be receiving recharge from the bedrock. A careful study of the water quality and water levels in progressively deeper wells in this region could be made to verify the recharge-discharge relation.

Isopach and Transmissibility Maps

Another method useful in determining quantitative information about an aquifer is the use of isopach or rock thickness maps. The isopach map used herein was compiled by determining the total thickness of sand and gravel between an elevation of 1400 feet and bedrock. The thickness of these deposits in each well was then plotted on a base map and contoured using a ten-foot contour interval. Although this type of map is commonly made for separate intervals, that is intervals that conform to the same thickness represented by each lithofacies map, it appears that each sand and gravel unit within the buried valley is inter-connected and reacts as a single hydrologic unit therefore, only one map including the total unit thickness was made (Refer to plate 5).

It can be seen by comparing the isopach with the lithofacies clastic-ratio maps, that the isopach map provides a good overall trend of the aquifers in the buried channel.

The main aquifer in tributary 1 is seen to be over 100 feet thick in the middle of tributary 1. The sand and gravel deposits gradually thin moving north into the mainstem valley. The sand and gravel reach a thickness of approximately 50 feet where tributary 4 enters the mainstem. The map shows that tributary 2 was a good source of sand and gravel, seemingly distinct from that of tributary 1. In most cases the isopach map closely parallels the results of the lithofacies-clastic ratio maps. Thus a good starting point in an aquifer study may include isopach maps, which could then be refined by knowledge from other maps such as lithofacies.

It should be noted that isopach maps have been used in conjunction with lithofacies clastic-ratio maps to determine the total quantity of water in storage, the quantity of water in storage available to wells, and transmissibility of the water-bearing materials (Pettyjohn and Randich, 1966). In this report a transmissibility map (plate 7) was prepared using the isopach map and permeability data from well tests. A permeability value given each test hole was multiplied by the sand and gravel thickness taken from the isopach map, thus giving a transmissibility value for each test hole.

Center of Gravity Map

Conventional facies maps are designed to show areal variations of rock type or composition of a stratigraphic unit. This aspect or change can be expressed in many ways. In dealing with the hydrologic properties of glacial drift, lithologies may be expressed by various maps, but experience has shown that no single number or symbol completely expresses the whole aspect of a stratigraphic section.

Krumbein and Libby (1957) have applied moments to vertical variability maps of stratigraphic units. The distinction between conventional facies maps and vertical variability maps is that facies maps show areal variation in absolute or relative amounts of lithologic types while vertical variability maps take into account the individual beds and their placement in the section.

Krumbein and Libby (1957) in using moment maps to show vertical variability, were dealing with widespread sedimentary units of Cretaceous age. In this report a preliminary application of the first moment or center of gravity map was used in glacial deposits to help interpret the geohydrology of the Minot area. The techniques are similar, but much greater changes exist in rock thickness and position in glacial deposits than in widespread bedrock formations.

The mean position or center of gravity of sand and gravel occurrences and their position in the section, were determined from the logs of wells and test holes published in Akin (1947), Pettyjohn and Hills (1965), and Pettyjohn (1968), as well as from unpublished data. The center of gravity for the sand and gravel beds between an elevation of 1400 feet and bedrock was computed for each log. The distance below an altitude of 1400 feet was measured for each sand or gravel bed and multiplied by the thickness of each bed. The sum of the products were divided by the total sand and gravel thickness at that location, thus providing the center of gravity, in feet, below an elevation of 1400 feet. Consequently, the calculated center of gravity takes into consideration the thickness of individual sand and gravel beds, and is also the weighted arithmetic mean position of probable good aquifers.

The computed center of gravity for each well log was plotted on a base map and contoured with an interval of 10 feet. The contours express the mean position of the sand and gravel beds in feet below the 1400 foot datum.

The center of gravity map (plate 6) may be interpreted in various ways. Going west in tributary 1, a distinct drop in the center of gravity is seen. This could be interpreted as the introduction of a different aquifer much lower than the main one, from the area of tributary 2. This relationship would not be shown on a conventional map such as a sand and gravel isopach (plate 5). The isopach map alone suggests a single major aquifer trending through the eastern part of the valley, whereas the center of gravity map may suggest two different aquifers, one an average of 30 feet lower in the section.

Although the center of gravity maps have probably not been used in glaciated areas before, they may be quite useful in geohydrologic studies. The second and third moments, standard deviation and skewness, respectively, which were used by Krumbein and Libby (1957) should add much to the usefulness of the mean position maps. These maps used in conjunction with facies maps such as sand gravel isopachs may be helpful in determining locations and distinctions between different aquifers. Further study of these maps as applied to glacial deposits will be necessary to see their true value.

SUMMARY AND CONCLUSIONS

The buried preglacial valley of this study trends north-south through Minot, North Dakota, with a major tributary entering from the east. After determining the configuration of the bedrock surface, It was decided to study only the valley fill deposits that lie below an altitude of 1400 feet. The drainage system developed on the bedrock, aquifer thickness, and potential for development were defined on the basis of well log data. The compiled data were subsequently analyzed and compiled into: bedrock contour, lithofacies clastic-ratio, isopach, center of gravity, and transmissibility maps. These evaluation techniques by themselves are useful but, when used in conjunction with each other, their value is greatly enhanced.

In the study area, the aquifer with the greatest potential for development contains approximately 110 feet of sand and gravel along the axis of tributary 1. While the sand and gravel isopach appears to indicate only one deposit, the center of gravity map suggests that there are two different 'sedimentary units'. Because of complex lithologic changes and limited extent of any one deposit, all the sand and gravel units are probably hydrologically connected.

Another area where later ground water development may be feasible is near the vicinity of the confluence of tributary 4 and the mainstem valley. At present, many Minot city supply wells are located in this area, but they are pumping water from a shallower aquifer and most of the wells do not penetrate the pre-glacial valley below an elevation of 1400 feet.

Although areas of high transmissibility are of prime importance in a geohydrologic study, areas of low potential must also be studied. Besides the sand and gravel deposits, the hydrology of the glacial till and fluvial deposits in the pre-glacial valley are of great value to the overall study. Pumping tests at various test holes have shown that the fluvial deposits, although having a low permeability, have a high porosity and storage capacity. These sediments could thus provide considerable recharge to the sand and gravel. Glacial till deposits, which occupy much of the mainstem valley, are, unlike the fluvial silts, very low in storage capacity and permeability.

Thus by combined use of the techniques described, much of the geohydrology of an area can be shown, including areas with high or low potential for ground water development.

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